

Disposal of End-of-Life Lithium-Ion Plug-In Electric Vehicle Batteries - Challenges and Open Questions
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Introduction

We are at the cusp of urgently needing to address disposal of lithium-ion plug-in electric vehicle (PEV) batteries.¹ Current PEV batteries have a lifespan of about 8-10 years, which means that the batteries from the first boom in PEVs will be reaching end-of-life in their primary application around 2020, and continuing on an exponential growth pattern through to 2050.² Bloomberg New Energy estimates that 311,000 metric tons of PEV batteries will have stopped working by 2025 alone — the same weight as almost 200,000 2018 Nissan Leafs.³ With massive PEV growth as a central component of our electric transportation future, end-of-life solutions for their lithium-ion batteries is necessary. Their size, and potential risks if mishandled, necessitate responsible disposal, recycling, and repurposing. Dumping these batteries into landfills is an unacceptable option, so feasible alternatives for disposal must be identified. Re-purposing of PEV batteries in home and commercial energy storage is being explored through case studies, and holds some promise, but has yet to be proven at the large scale that will be necessary. No large-scale specialized recycling facilities currently exist for lithium-ion PEV batteries, and current recycling processes have not been proven capable of extracting enough materials to make a profit. Re-purposing and recycling both have potential, but challenges include a lack of standardization across battery manufacturers, logistical and economic challenges, and an uncertain regulatory climate.

Re-purposing of PEV batteries

When an PEV battery reaches its end of useful life within a vehicle, it still retains about 70% of its capacity and could potentially be usable in other applications for an additional 10 years, indicating that re-purposing is a serious possibility.⁴ Research and small-scale trials have explored re-purposing PEV batteries for home and commercial energy storage. Used PEV batteries could be used to store energy from the grid when it is cheapest or operating on renewables to use throughout the day, which could reduce peaker plant operations by 10-20%, reduce greenhouse gas emissions, and delay battery

¹ While most PEVs use lithium-ion batteries, some cars that have electric motors use batteries that are not lithium-ion. Most prominently, Toyota has used nickel metal hydride batteries in many Prius models. This memo focuses exclusively on lithium-ion batteries, which are the predominant battery used in electrified vehicles.

² <http://www.energy.ca.gov/2016publications/CEC-500-2016-051/CEC-500-2016-051.pdf>

³ <https://www.bloomberg.com/news/articles/2017-12-01/the-cobalt-crunch-for-electric-cars-could-be-solved-in-suburbia>

⁴ <https://www.nrel.gov/transportation/battery-second-use-analysis.html>

recycling.⁵ NREL research suggests that the potential savings on demand and time-of-use charges from this solution could recoup investment in less than seven years of operation.⁶

PEV drivers could benefit from these energy storage solutions if this repurpose market takes off. Early studies suggest that a used battery could be worth several thousand dollars.⁷ If automakers assumed the responsibility for recovering and re-purposing batteries, they could use the anticipated second-use value of the batteries to lower the cost of PEVs to consumers, accelerating market development.⁸ While drivers may not ultimately benefit from the full potential value of their end-of-life batteries as there may be a greater supply than there are sensible applications,⁹ NREL research suggests that even if the value of a battery is not able to significantly offset the cost of an PEV, it should at least offset vehicle end-of-service disposal fees.¹⁰

There are a number of concerns around the feasibility of battery re-purpose for energy storage. Tesla Chief Technology Officer JB Straubel is the most forceful critic of using used PEV batteries for this purpose. He argues that the technology found in these batteries will be a decade old by the time they would make it to the second-use market, making them ineffective for application; that used batteries will be prone to failure and cannot provide the reliability necessary for storage; and that PEV batteries are not designed to cycle multiple times daily as energy storage batteries would be expected to. He argues that the energy storage market will ultimately be dominated by specialty batteries rather than re-purposed ones.¹¹

There are also significant logistical hurdles in the supply chain needed to actualize this vision. No company has yet emerged to take on responsibility for sourcing thousands of batteries from individual vehicles, testing them to ensure their function, assuming liability and warranty for potentially unreliable used batteries, and ultimately using or selling non-standardized batteries in bulk. Because battery management systems - the software that automakers and battery manufacturers use to assess the health of a battery - are not standardized, batteries from different vehicles cannot be easily received, processed, and assessed in bulk.¹² Start-ups such as IT Asset Partners¹³ and Spiers New Technologies¹⁴ have developed partnerships with some automakers to evaluate the capacity and re-purposeability of

⁵ <https://www.nrel.gov/docs/fy15osti/63332.pdf>

⁶ <https://www.nrel.gov/docs/fy12osti/53799.pdf>

⁷ https://www.law.berkeley.edu/files/ccelp/Reuse_and_Repower_--_Web_Copy.pdf

⁸ <http://www.sciencedirect.com/science/article/pii/S0378775311012377?via%3Dihub>

⁹ <https://www.nrel.gov/transportation/battery-second-use-analysis.html>

¹⁰ <https://www.nrel.gov/transportation/battery-second-use.html>

¹¹ <https://cleantechnica.com/2016/08/22/vehicle-to-grid-used-ev-batteries-grid-storage/>

¹² Meeting with California Air Resources Board Air Resources Engineer Ryan Hart, March 6, 2018.

¹³ <https://www.cnet.com/roadshow/news/for-dead-ev-batteries-reuse-comes-before-recycle/>

¹⁴ <https://chargedevs.com/features/second-life-spiers-new-technologies-develops-advanced-battery-classification-techniques/>

second-life PEV batteries, but It is unclear whether more companies will jump into this high-effort work, especially as returns are far from guaranteed.¹⁵

A few small pilot projects have explored re-purposing of PEV batteries. Nissan has partnered with the energy storage provider Green Charge Networks to commercially sell energy storage systems built from recycled LEAF batteries to businesses, General Motors is working towards a similar system with its Volt batteries,¹⁶ and BMW is partnering with Swedish power company Vattenfall to do the same with i3 batteries.¹⁷ BMW and PG&E conducted a joint study testing second-use batteries as energy storage for demand response.¹⁸ Startup Freewire runs mobile concierge PEV charging stations from recycled batteries.¹⁹ The Center for Sustainable Energy has done several trials focusing on developing protocols to monitor battery performance in second-life applications, and the CEC has conducted research on trial cases and funded several projects such as a BMW-UCSD energy storage collaboration.²⁰

Recycling PEV batteries

Recycling PEV batteries is challenging. No solutions have been proven at scale as cost-feasible and/or able to recover all or nearly all of the materials in the battery. BEV batteries also have more toxic substances than household and internal combustion vehicle batteries, meaning that improper disposal is a toxic waste hazard.²¹ While recycling BEV batteries has great potential, such as cutting world lithium demand from 450 metric tons to 100 metric tons by 2050,²² the technology remains unproven.

No recycling solution for recycling PEV batteries has yet been proven as viable and scalable. Currently, the materials recovered from fully recycling a PEV lithium-ion battery are worth only a third of the cost of the recycling product, primarily because the lithium, the most valuable part of the battery, cannot be easily extracted.²³ This makes for a challenging business case for recycling. Some recyclers claim to have developed methods to make a profit from lithium-ion battery recycling, but none have yet been proven

¹⁵https://www.greencarreports.com/news/1103363_reusing-electric-car-batteries-great-idea-lots-of-practical-challenges

¹⁶ Neither are commercially available yet. <https://www.nytimes.com/2015/06/17/business/gm-and-nissan-reusing-old-electric-car-batteries.html>

¹⁷ <https://electrek.co/2017/03/20/bmw-i3-battery-packs-energy-storage-vattenfall/>

¹⁸https://www.greentechmedia.com/articles/read/bmw-and-pge-prove-electric-vehicles-can-be-a-valuable-grid-resource#gs._PpN=jw

¹⁹<https://www.fastcompany.com/3049018/this-mobile-charging-station-runs-on-scrapped-batteries-and-comes-right-to-your-electric-car>

²⁰ <http://www.energy.ca.gov/2016publications/CEC-500-2016-016/CEC-500-2016-016.pdf>

<http://www.energy.ca.gov/2016publications/CEC-500-2016-051/CEC-500-2016-051.pdf>

http://www.energy.ca.gov/research/energystorage/tour/ev_batteries/

²¹<http://americanrecycler.com/8568759/index.php/news/category-news-2/2643-recyclability-of-electric-vehicle-batteries-scrutinized>

²² <https://anl.app.box.com/s/7lgwlmm5isrsyfae13dwxlz1bn9gjxhi>

²³<https://www.theguardian.com/sustainable-business/2017/aug/10/electric-cars-big-battery-waste-problem-lithium-recycling>

at scale.²⁴ The most prominent, Umicore Battery Recycling, has signed battery recycling contracts with Toyota, Renault, Nissan, Daimler, and Tesla, but they are tight-lipped about details.²⁵

CEC research estimates that California's rate of PEV battery disposal will not reach commercial viability until 2050.²⁶ Similar problems exist internationally: in the EU, only 5% of all lithium-ion batteries are currently recycled, with the rest incinerated or dumped into landfills.²⁷ Because of this, re-purposing currently presents a more appealing option.

Lack of standardization also makes reliable recycling a challenge – each could require a different recycling procedure and potentially even separate facilities.²⁸ Additionally, recyclability has not been a priority in the design of PEV batteries: battery makers have been pushed to optimize primarily for performance and other technical specifications.²⁹ Argonne National Laboratory research finds that design for recycling would include distinguishing labels or similar features, format and component standardization, similar materials and chemistries, and easily separable parts.³⁰

Challenges and open questions

Challenge: Standardization. A heterogeneous pool of PEV batteries is a major obstacle to both the re-purposing and recycling markets. Each PEV manufacturer sources different chemistries and designs. This makes it challenging to dispose of batteries at scale: different inspection techniques and procedures would be needed for each kind of battery to certify them capable for re-purpose, and different chemical processes would have to be developed and implemented to recycle each one. However, automakers have legitimate competitive reasons to resist standardization. Experimenting with different battery formats helps drive economic and technical innovations in PEV development. Additionally, since the battery is one of the major components of a car, the whole car is designed around it - thus, batteries vary in size and density accordingly to allow for different form factors. There may be more potential in standardizing battery management systems and battery health metrics, which would allow a company receiving batteries for second-use applications to easily take in batteries from different vehicles and manufacturers and process them quickly using common standards.

²⁴<https://www.bloomberg.com/news/articles/2017-12-01/the-cobalt-crunch-for-electric-cars-could-be-solved-in-suburbia>

²⁵ https://egvi.eu/uploads/2_4%20Jan%20Tytgat_Umicore.pdf

²⁶ <http://www.energy.ca.gov/2016publications/CEC-500-2016-051/CEC-500-2016-051.pdf> The CEC has also funded research suggesting that direct recycling, modeled after the recycling practices of the lead acid battery industry, would present a viable recycling strategy. <http://www.energy.ca.gov/2016publications/CEC-500-2016-016/CEC-500-2016-016.pdf>

²⁷<https://qz.com/1088195/chinas-booming-electric-vehicle-market-is-about-to-run-into-a-mountain-of-battery-waste/>

²⁸ <http://www.sciencedirect.com/science/article/pii/S2214993714000037>

²⁹ americanrecycler.com/8568759/index.php/news/category-news-2/2643-recyclability-of-electric-vehicle-batteries-scrutinized

³⁰ <https://anl.app.box.com/s/iamwuwt4s4dd4f40f253zha43fjhii2f>

- **Open Questions:** How can standardization be promoted in a way that does not inhibit the growth of the industry, and what aspects would be most important to standardize?

Challenge: Logistics and economics of disposal. A re-purpose economy faces significant supply chain challenges, requiring market actors to invest in sourcing large numbers of batteries, running safety and diagnostics tests on them to determine their suitability for re-purposing, identifying second-life applications, and installing them as appropriate. No PEV battery re-purpose applications have reached substantial scale, and the economic viability of the process remains unproven. Recycling faces similar challenges, with a non-standardized supply chain involving sourcing large batteries from many different vehicles and as-of-yet-unproven economic viability.

- **Open Questions:** Would different actors emerge to take on each of these logistical functions, or will actors emerge to take on the entire supply chain? Where would recycling facilities be located? What role would the state play in incentivizing recycling? How can the state promote research that will identify scalable market-viable solutions?

Challenge: Re-purpose versus recycling. It remains unclear whether or not one of these processes will prove to be the most effective and economical, if there will remain a role for both, or, if neither will prove viable at large-scale.

- **Open Questions:** Given that both approaches remain new and unproven, how can the state promote the development of both until more is known about economic and logistic viability? Should the state eventually focus research, funding, and regulation on both re-purposing and recycling, or just one? During the interim, and if neither process proves viable at large-scale, how can the state ensure safe disposal given the risk of toxicity if they are mishandled?

Challenge: Understanding where batteries are currently going. It is unclear where exactly PEV batteries are currently going after their vehicles are decommissioned. The top priority must be to divert these batteries from landfills, and so understanding the current situation is vital for identifying progress towards this goal.

- **Open Questions:** Are batteries being stored in warehouses? Are they being shipped to other countries? Are they being taken to landfills? How can we identify where these batteries are going, and if any are currently going to landfills, what steps can be taken to divert them?

Challenge: Role of state regulation. As of yet, there is little state regulation surrounding PEV battery disposal. While this currently allows some freedom, it also creates an uncertain future regulatory picture for the industry. Some battery re-purposing test projects have been inhibited by lack of short-term experimental access to the grid, and other energy storage regulations that were not written to be inclusive of second-use batteries.

- **Open Questions:** How can the state create regulations around PEV battery disposal without inhibiting innovation? How can the state create regulations that will support research and development in a growing market space?

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